# Origin of rollovers and monoclines in the Koae fault zone, Kilauea Volcano, Hawaii

**Brian Lehnerz**
Department of Geology. Pomona College, 609 N. College Ave., Claremont, CA 91711-6356
*Faculty sponsors: Linda Reinen, Pomona College; Richard Hazlett, Pomona College*

## INTRODUCTION

The Koae faults are very tectonically active, and have been so for at least 1500 years based on the ages of the lava flows they cut. This system of faults links the Southwest Rift Zone with the East Rift Zone of Kilauea. The numerous tectonic episodes have caused horizontal, vertical, and local strike-slip movement along the faults. The faults consist of numerous fractures, arranged en echelon, which define a continuous fault system 12 km long and 2 km wide (Duffield, 1975). They strike in a sinuous manner and are best described as steeply dipping normal faults with north-facing scarps. Studies indicate that dilation along the faults is probably due to the forceful injection of dikes primarily in and around the rift zones and/or gravity-driven slippage of the south flank of Kilauea towards the sea (Duffield, 1975). The origin of the Koae fault zone is somewhat uncertain, especially when one considers that most of its scarps dip northward, while other scarps on the south flank of Kilauea dip to the south as a series of detachment faults along an underlying décollement.

Two of the most impressive structural features associated with the Koae faults are those of the monoclines and rollovers on the downthrown block. The purpose of this study was to look at these features along a portion of the southernmost Koae fault (Figure 1) and determine how the monoclines and rollovers formed given the structural regime of the area.

## METHODS

First, the area of study was mapped, and in particular, the following features are highlighted (Figure 1): trend of the master fault, trend and opening directions of cracks on the downthrown block, and lastly, location and structural features of monoclines and rollovers. The upthrown block is not mapped because it lacks significant structural features. Transects were then constructed along the length of the fault at locations which coincided with important structural features (Figure 1). All measurements were made with a standard Brunton compass and tape measure.

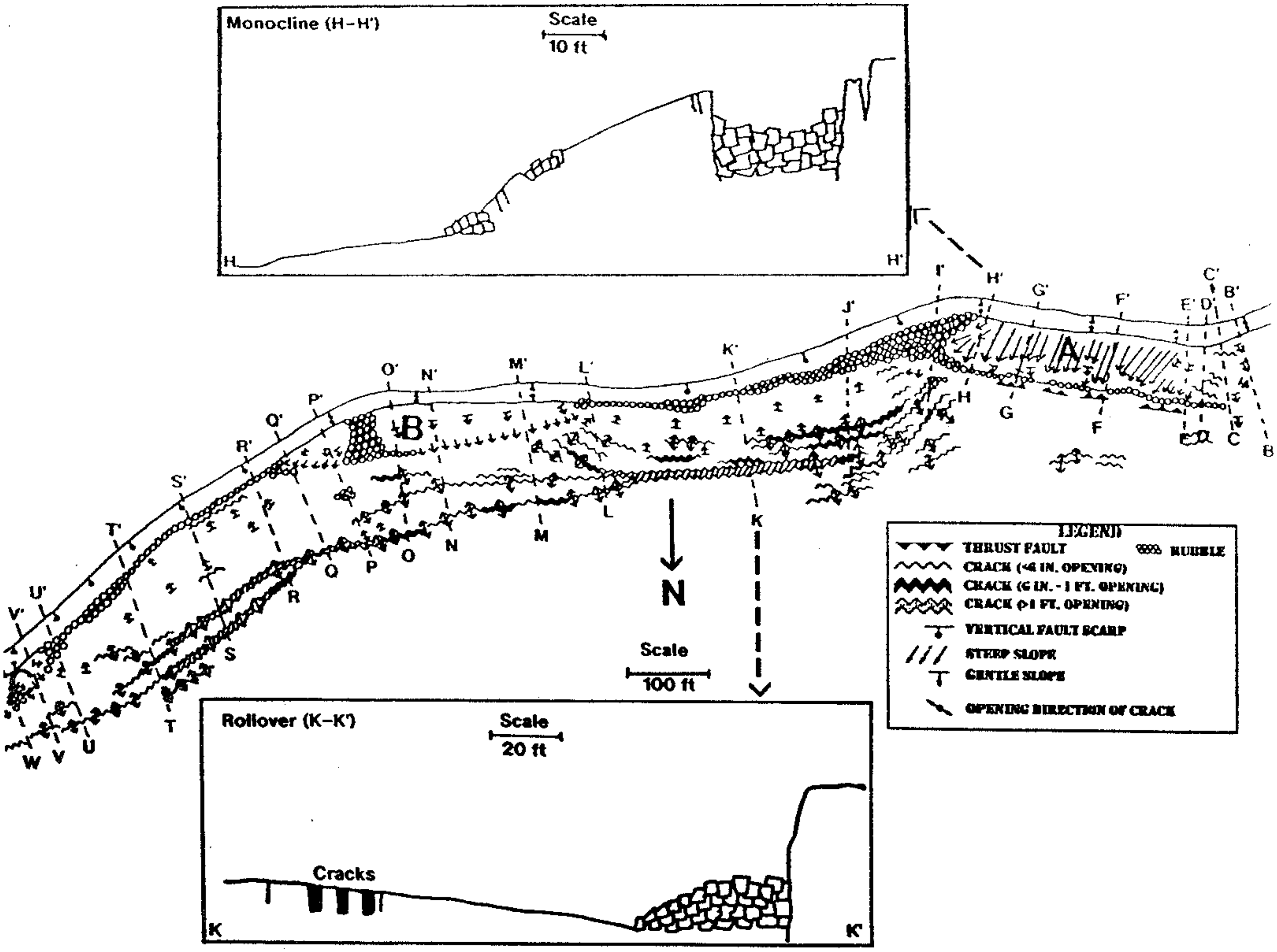
I used Microsoft Excel to construct several slip-distribution models (Figure 2) along the length of the fault. Several stress orientation maps were also created based on the opening direction of the cracks (i.e. the opening direction is sigma3). These stress orientation maps enabled me to construct rose diagrams (Figure 3) documenting the stress domains along the fault. The trends of the fault scarps and the long axes of the monoclines were also entered into rose diagrams for comparison with one another and with the opening directions of the cracks.

## RESULTS/DISCUSSION

**FAULTS:** Figure 2 shows that slip along the fault increases from west to east, or B-B' to W-W'. These results agree with the work of other geologists (e.g. Duffield, 1975) who have shown that offset along the fault increases towards the more active, eastern rift zone. Also, the graphed area covers approximately the western 1/4 length of the fault which means that, according to ordinary fault slip-distribution models, the slip should at least be increasing towards the a maximum slip at the center of the scarp (as seen in Figure 2). The fault scarps trend between N50E and N100E with most of the scarps oriented N75E to N80E (Figure 3). A more perplexing observation, however, is that the scarp along the monoclines is in many places offset more than the scarp along the rollovers (Figure 2). This problem remains an open question.

**CRACKS:** Prominent cracks on the downthrown block are seen in Figure 1. These cracks appear primarily along the rollovers near their apices. The cracks dilate towards the center of the rollovers and narrow again at the ends of the rollovers. Figure 3 shows that the opening directions of the cracks trend primarily in a N10W to N30W direction (often causing left-lateral offset with the trend of the cracks). Such dilation could be accounted for if it was occurring from dike propagation in a southeast manner from the Southwest Rift Zone which lies to the northwest of the Koae faults. One unexplained anomaly in the opening direction of the cracks, however, is that of the transition between Monocline B and the rollover to the west in which opening

Figure 1: Map and Transects of Fault



directions are N30E to N40E. The final observation of the cracks associated with the rollovers is that they often curve towards the main fault scarp on either end of the rollover (Figure 1). Such curving provides for a bowl-shaped rollover.

**ROLLOVERS:** A topographic profile across a typical rollover is presented in the inset in Figure 1. The rollovers mostly have slopes between 2 and 10 degrees. The steeper the rollover, the larger the cracks at its apex. The rollovers represent dilation in a NW-SE manner as most are oriented perpendicular to this direction (Figure 1). Such dilation could coincide with dike propagation perpendicular to the Southwest Rift Zone. Accordingly, this observation coincides with the dilation of the cracks themselves, as mentioned above. Withjack, et. al (1995) modeled rollovers using clay and sand, and also used other geologists' models, to conclude that rollovers form through dilation when the underlying fault is listric. Such fault geometry is likely in this area as well. An initially steep, listric fault that is dilated in the manner described above, could form the large-scale rollovers found in this study area.

**MONOCLINES:** A topographic profile across a typical monocline is given in the inset in Figure 1. The monoclines generally have slopes between 30 and 50 degrees, but can be 10 to 75 degrees locally. The monoclines are oriented in both a N45E to N60E manner and in a N80E to N110E manner. The overall orientation of the monoclines is different than that of the fault scarps which are mostly oriented N75E to N80E (Figure 3). Macdonald (1957) presented a model for how these monoclines form. As the fault offsets vertically, the overlaying layers of basalt flex and eventually break from the movement. An anticlinal bend develops on the upper portion of the flexing layers along which a wedge-shaped crack eventually develops from the tension. The synclinal bend develops on the bottom portion of the layers, along which a zone of compression develops and is recognized by a crushed, rubbly zone. Figure 1 shows that such a model fits the present appearance of the monoclines in this area. Also, Withjack, et. al (1990) modeled monoclines using sand and clay and found that a steeply dipping fault through a multi-layered fairly homogenous medium (comparable to numerous layers of basalt) will produce similar results as those in Macdonald's models. The monoclines probably formed after the initial faults broke when the northern block dropped down in relation to the southern block. Such fault scarps were oriented similar to the orientation of the monoclines today. Later, with continued dike propagation from the Southwest Rift Zone, the fault began dilating and areas perpendicular to the dilation (which did not include the monoclines) deformed by cracking and rolling over into the scarps, eventually connecting to the scarps where the monoclines are found. When viewed in the field the monoclines and rollovers alternate with one another along the length of the fault.

## CITED REFERENCES

Duffield, W.A., 1985, Structure and origin of the Koae fault system, Kilauea Volcano, Hawaii: USGS Professional Paper 856, p. 1-9.

Macdonald, G., 1957, Faults and monoclines on Kilauea Volcano, Hawaii: USGS Professional Paper, v. 68, p. 269-271.

Withjack, M. O., Olson, J., and Peterson, E., 1990, Experimental models of extensional forced folds: AAPG Bulletin, v. 74, p. 1038-1054.

Withjack, M. O., Islam, Q. T., and La Pointe, P. R., 1995, Normal faults and their hanging wall deformation: An experimental study: AAPG Bulletin, v. 79, p. 1-18.

**Figure 2: Slip Along Length of Fault (B-B' to W-W')**

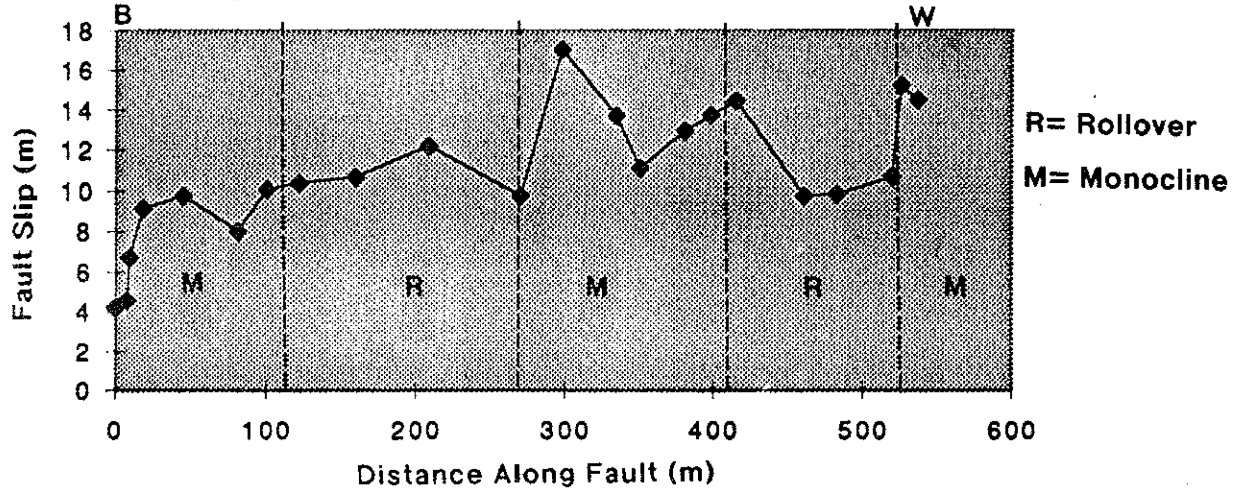
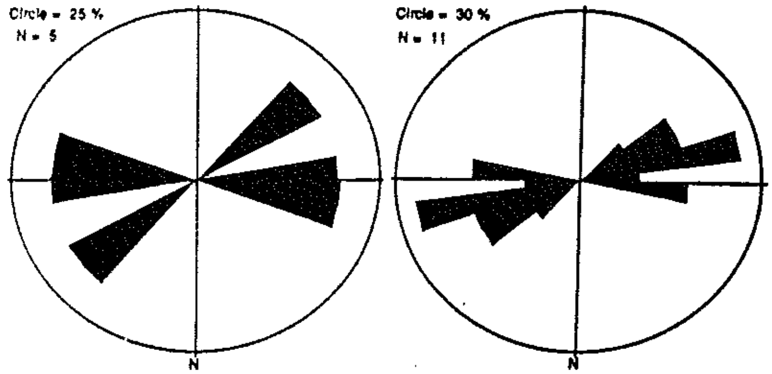


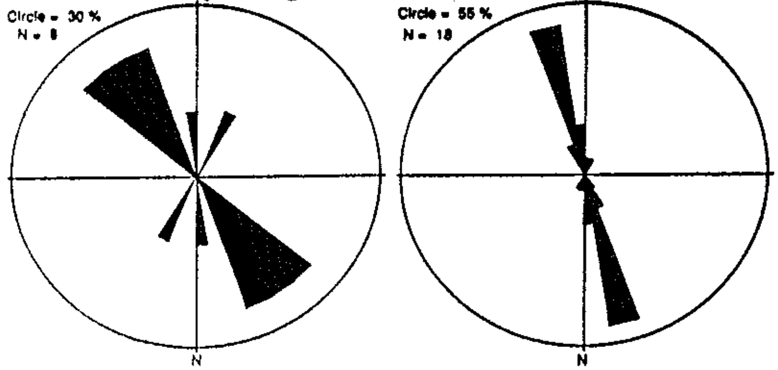
**Figure 3: Orientation of Trend of Faults and Monoclines, and Opening Direction of Cracks**



Orientation of Monoclines

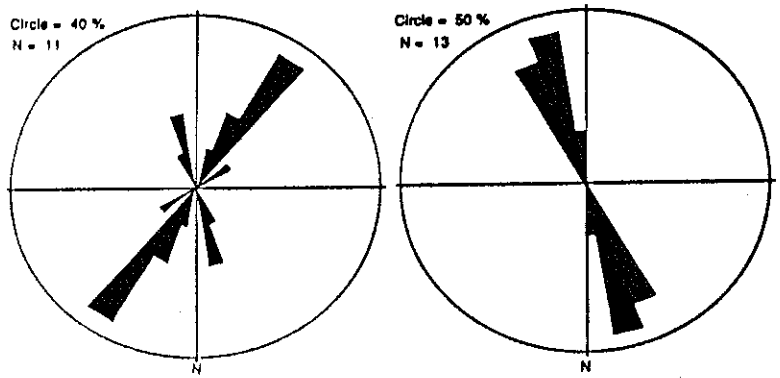
Trend of Fault Scarps

## Opening Direction of Cracks



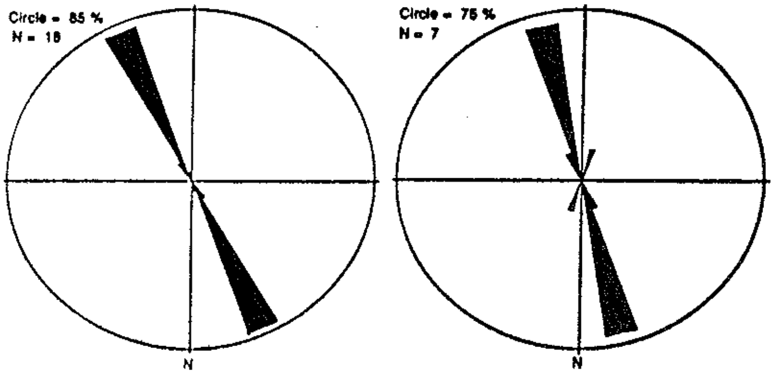
Transition Between Monocline A and Rollover to the East

Rollover Between Monocline A & B



Transition Between Monocline B and Rollover to West

Along Monocline B



Rollover Between Monocline B & C

Transition Between Monocline C and Rollover to West